Dynamic Studies of the Scientific Strengths of Nations Using a Highly Detailed Model of Science

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Introduction

The traditional approach to measuring the scientific strength of nations is to count articles and/or citations by discipline. Sources such as the biannual Science & Engineering Indicators Reports (SEI) track these values by year, enabling national leadership trends to be shown. Fields or disciplines in these studies are broadly defined (e.g. physics, chemistry, clinical medicine), and are typically based on journal categories.

We argue that the traditional discipline-based approach to measuring scientific leadership is obscuring actual patterns of scientific leadership. For example, according to the method adopted in the SEI report, neither Germany nor the United Kingdom are leaders in any disciplines in physics or chemistry (1). This is counter to common knowledge and common sense. Something is fundamentally wrong with this traditional measurement approach.

In this paper we present a new method for measuring and visualizing the scientific strengths of institutions and nations. We will show how this measurement technique is far more accurate than the traditional discipline-based approach. We will also show how this new technique can effectively visualize the evolution and dynamics of scientific strengths in the U.S. and China.

Methodology

The traditional approach of counting articles and/or citations by discipline inherently assumes that strengths of an institution are built along disciplinary lines. This is simply not true, and gives a highly misleading assessment of scientific strengths (1, 2). We have found that strengths are almost always composed of an assembly of scientific paradigms, are either sub-disciplinary or interdisciplinary in nature, and thus cannot be accurately described or measured using any discipline-based categorization system. Assemblies of paradigms as strengths are idiosyncratic to each institution (e.g., university, state or nation). We have thus developed a very fine-grained reference paper-based classification system that allows the strengths of an institution to be defined and assembled in great detail, and visualized over time.

Briefly, our methodology is as follows. First, we create a separate, detailed model of science for each publication year using co-citation techniques (1). Co-citation techniques are well established and represent the way in which scientists have self-organized into communities. Each annual model is comprised of roughly 2M highly cited reference papers and 5M+/- papers from the model year and previous four years that cite the reference papers, and is grouped into roughly 80,000 separate clusters, or paradigms. Each paradigm has a distinct topical focus. Each annual model thus has a four year overlap of current papers with the previous years' model. This forms the basis for linking the annual models over time.

Once the models have been created they can be used to identify the strengths of an institution. This is done by finding all of the paradigms in which the institution has a high relative market share, and then linking those paradigms using the unique publication pattern of the institution. Groups of paradigms that are purposefully linked by the researchers at an institution form the competencies of the institution; those competencies in which the institution has a leadership position, whether in terms of current or reference publication counts, or velocity

or impact, are the *strengths* of the institution. Paradigms can be clustered to show either a static (using a single year's model), or dynamic (using models from multiple years) picture of strengths.

We have used this method in previous studies to show the research leadership of a university and of several nations for single years. In the case of the university, this new approach was able to identify ten areas in which the University of California at San Diego (UCSD) has research leadership, while a discipline-based approach showed only one (2). At the national level, this approach identified multiple areas in chemistry and physics where Germany and the UK had strengths, while the discipline-based approach did not identify any of these areas (1). These studies have shown that our new methodology gives a much more accurate picture of the actual strengths of an institution than do the currently accepted discipline-based approaches to ranking.

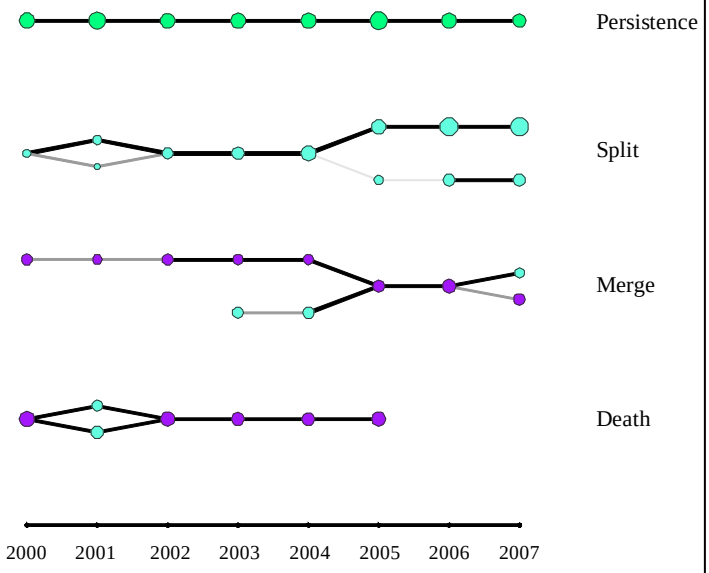

Figure 1. Examples of evolutionary types associated with strengths of a U.S. university. Colors denote the dominant discipline for the strength (purple: physics, blue: engineering, green: biology).

Preliminary Results of Dynamics Studies

Studies of university strengths have recently been extended to show the dynamics of those strengths over time, by sequentially linking models from the 2000-2007 model years for a U.S. university. Overlaps between the model years are based on 4-year sliding windows. We find that some strengths are persistent over time (although they may expand or contract in size), some split and merge, some go dormant and then reappear, while others are small and only appear for a short time. Example visuals of several of the dynamic types associated with actual strengths in a U.S. university are shown in Figure 1.

The full paper, if accepted, will extend these studies to show the dynamic strengths of nations, particularly the U.S. and China, and will validate the strengths and their trends using temporal views of both topical and author profiles. Strengths of nations will be calculated following the method in (1), and will be linked using the method described briefly above, and that has been used for studies of the dynamics of university strengths, such as those shown in Figure 1.

References

1. KLAVANS, R. & BOYACK, K. W., An objective, reliable and accurate method for measuring research leadership, *Research Evaluation*, under review (2009).
2. KLAVANS, R. & BOYACK, K. W., Identifying distinctive competencies in science, *Journal of Informetrics*, under review (2009).